A Computerized Method to Diagnose Strabismus Based on a Novel Method for Pupil Segmentation

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Abstract—**Strabismus is a disease of the human visual system in which the eyes are not properly aligned which results in gazing in different. This paper presents a computer vision driven method for a quantitative decision support in the diagnosis of the disease. An infrared (IR) camera with IR illumination is used to capture the patient eyes. The proposed method estimates the normal vectors of both pupils, and measures the enclosed angle in real-time while the patient gazes at different predefined points. The three main processing steps in the proposed algorithm are: (i) Eye detection using Haar features combined with an Adaboost classifier. (ii) A novel method was developed to detect the ellipse of the pupil in the image frame; this method uses a line integral to detect the pupil ellipse in real time. (iii) Estimation of the pupil normal vector based on the parameters of the segmented pupil ellipse. All three methods were evaluated on real human eyes and on an eye model.**

I. Introduction

Strabismus is a visual problem in which the alignment of the eyes is not proper but they point in dissimilar . One eye may be looking in straight direction, while the other turns in another direction. The eyes misalignment may be consistent or temporal. The basic symptom of Strabismus is a visible misalignment of the eyes. When there is obvious and large misalignment, the Strabismus is called "large-angle." Less misalignment is known as small-angle [1], [2].

An eye is blessed with six external muscles which are responsible for positioning and monitoring the position of the eye. For a person to have standard binocular vision, the position, functioning and neurological control of these muscles must be coordinated adequately for the pair of eyes. Strabismus occurs in the circumstances when the body has neurological or anatomical complications that hinder controlling and functioning of the extraocular muscles. Genetics also play a comprehensive role: If a person has Strabismus, the offsprings are on certain risk of developing Strabismus as well. Various eye tests can be used for a better diagnosis of Strabismus [4], [3]. Disputing about diagnosis tools means disputing about the accuracy, speed, cost and flexibility. Strabismus is diagnosed based on a conventional ways so far. Hess test represents one of them [5]. It is composed of a printed network of red nodes connected by red lines, a goggle with a red lens on one eye and a green lens on the other, and a portable green light illumination. The patient is required to wear the goggle and project the illumination on one of the red nodes. The dissociation between the red node and the projected green spot represents the level of Strabismum which can be measured by the Hess network. Hess test has the following cons:

- It is required to be controlled by a professional supervisor and it is founded only in clinics. Therefore, it is not flexible and costly
- It is not accurate because it is sensitive to stability of the patient head during the test.
- It is slow

(David et al,1989)[6] introduced a computerized form of Hess test. It replaces the printed network with a computer screen and the illumination with a joystick. This system overcomes the flexibility, cost and speed problems of Hess test. However, it is still sensitive to the stability of the patient head. (Bakker, N et al,1999) [7] showed a recent method using two cameras based on 3D vision techniques. It estimates the 3D gazing vector of the patient eyes and then measures the Strabismus level. This method is accurate but it is costly since requires two cameras and the estimation of the patient head 3D position and then the pupil 3D coordinated. In this paper, a novel method of Strabismus diagnosis is shown. It uses only one camera to estimate the 3D gaze vector of the patient eye Independently on the 3D position of the patient head.The input of the system is a monochrome image of the patient face. Before the normal vector of the pupil is estimated, the pupil within the input image has to be located. The pupil is projected on the image plan as an ellipse.In this paper a novel method to locate the pupil and to estimate the ellipse coefficients (center coordinates, semi major axis, semi minor axis and the rotation angle) is shown. After that the ellipse coefficients with the focal lengths of the camera are used to estimate the gaze vector of the pupil.

II. Eye Gaze Vector Estimation

In this section, the estimation algorithm of the eye gaze is shown. The first step is to segment the eye region from the input face image. For this propose, an Adaboost classifier with Haar-like feature is used [8], [9].This method is accurate, commonly used and well explained in many literatures. The second step is to estimate the ellipse coefficients of the pupil. (J. Daugman et al. 2001)[10] introduced a method for iris/pupil localization based on circular line integral, but this method can not be used in our system since the pupil projection is an ellipse rather than a circle; especially if a the patient is gazing at points different from the camera center. Therefore, a line integral over an ellipse is used instead. This modification gives two advantages:

- A more accurate pupil segmentation
- A direct estimation of the pupil ellipse coefficients

The third step is to employ the estimated ellipse coefficients in the method given by (Haiyuan WU et al. 2003) [11] to estimate the gaze vector of the pupil; after considering the focal lengths of the used camera. By estimating the gaze vector of both patient eye, the angular difference between both vectors gives the level of Strabismus. Fig.1 shows a sample result of eye gaze vector estimation.

III. Evaluation and Conclusion

At the first phase of our work, we searched for the different types of strabismus and what are the reasons of each one. Generally, most of Strabismus types are diagnosed without a machine intervention. In our work, a computerized diagnostic approach using a digital camera directed to the patient face is introduced. To develop this algorithm, two research questions are addressed:

- How can we diagnosis the strabismus using the patient face image?

Since we are dealing with only the visible part of the human eyes, our proposed method works with a particular type of Strabismus that is the result of deficient synchronization between the extra ocular muscles which are responsible for the movement of the eyes. A single eye or even both eyes may suffer from this disorder. Strabismus prevents both eyes from focusing at a particular point. Another type of Strabismus is caused by the structure of the eye ball which causes blurred image. However, the visual lines of the eyes are still aligned. According to that, our proposed system cannot be used for this type of disorder. An intensive searching for machine vision algorithm that are close to our goal is done. Since the diagnosis of Strabismus is our goal, the eye represents the region of interest which has to be segmented from the input image. Many algorithms are proposed to detect and segment eyes in the face images. Haar features combined with an Adaboost strategy are used in our paper to detect the eye region. This method is a common, robust and fast. The eye region segmentation is a pre-step but it is not enough to diagnose Strabismus. The pupil of the eye is our target; its movement and 2D/3D positions are the goal parameters to be obtained. To detect the pupil region within the eye image, a novel method is developed. This method uses the line integral over an ellipse to fit the projected ellipse of the patient pupil. The outputs of this method are the 2D position of the pupil center and its ellipse coefficients. These two outputs are used to estimate the normal vector of the pupil eye. The general algorithm of our work consists of three steps: (1) Eye region detection (2) Pupil detection (3) Pupil normal vector estimation. (2) Pupil detection (3) Pupil normal vector estimation.

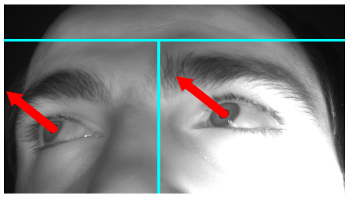

Fig. 1.
Estimated Gaze Vectors of Patient Pupils

- How Strabismus is diagnosed?

The developed algorithm from the second research question is applied on both patient eyes separately; the angle between the two normal vectors of the pupils is measured while the patient is gazing at different directions. If the tested person is healthy, the measured angle is small. Which means that the normal vectors of his eyes move almost parallel. If the measured angle is larger than a specified threshold (about ten degrees [1]), then the tested person may has a Strabismus. After the proposed methods are implemented, They have been evaluated and tested on human eyes on a real human eye and on a plastic eye model. This evaluation is done by comparing the estimated vector 3D angle with the actual (known) angle. The average error of all tests was 1.02 degree with a standard deviation of 0.2163 degree.

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